Vol. XI & Issue No. 2 February - 2018
INDUSTRIAL ENGINEERING JOURNAL

OPTIMIZATION OF BROACHING PROCESS USING DOE APPROACH

Ms. Jaya Valyan
Dr. Suraj Rane

Abstract

Design of Experiments (DOE) is a systematic and well-defined optimization techniques used in wide applications in industries and academic research. In this paper, a cylindrical component broached on a FIMAT machine with 14 fixtures is studied to optimize the CTQ; wall thickness. The wall thickness is defined as the step diameter minus the broaching depth. The objective is to optimize the parameter setting so that wall thickness meets part specification i.e. 1.15 to 1.35 mm. The process capability of the current process was found to be 0.68, which is very low on quality requirement resulting in 4.6 % defectives. It was decided to use Design of experiments approach to find optimal level of input parameters. Following factors were considered for conducting DOE; outer diameter, step diameter, type of fixture and broach blade height setting. The main effects and interaction effects were studied for their contribution to ANOVA. The outcome of the study was improvement in process capability and reduction in defective percentage.

Keywords – DOE, broaching, process capability, quality improvement, ANOVA

1. INTRODUCTION

Broaching is a material removal process for obtaining desired shape, width and depth usually in one stroke using a multiple-teeth cutting tool called broach. Usually, the work-piece is in fixed position and the cutting action takes place by moving the tool linearly relative to the job in the direction of the tool axis. However, in continuous broaching machine, the work-pieces are clamped in fixtures on an endless belt loop and moved past a stationary broach. The broach consists of a series of distinct cutting teeth along its length. Feed is accomplished by the increased step between successive teeth on the broach. The total material removed in a single pass of the broach is the cumulative result of all the steps in the tool. The shape of the cut surface is determined by the contour of the cutting edges on the broach, particularly the final cutting edge [1].

Research has been done previously on improving broaching process with respect to surface roughness [2], chip formations [3], and broach material [4]. In this study, the broaching process is used for making a rectangular cut in a cylindrical piece with a step. The output characteristic of our interest is wall thickness. The aim of this work is to optimize the broaching process in order to improve the process capability and reduce rejection. This requires that the CTQ parameter is maintained within specification limits of 1.15 to 1.35 mm. In the initial process capability study conducted for the existing process, the process capability is found to be 0.68 which is poor. Design of experiment approach is selected to identify the levels at which the control parameters must be set to improve the process performance. Design of Experiments (DOE) is a statistical approach to designing and conducting experiments such that the experiment provides the most efficient and economical methods of determining the effect of a set of independent variables on a response variable. Knowledge of this relationship permits the experimenter to optimize a process and predict a response variable by setting the factors at specific levels [5]. It is a method for carrying out carefully planned experiments on a process. By using a prescribed plan for the set of experiments and analyzing the data according to certain procedures, a great deal of information can be obtained from a minimum number of experiments [6]. Design of experiments helps to establish the cause and effect relationship between independent and response variable in an experiment. DOE has been used previously for applications such as optimizing die casting density and reducing porosity [7], studying the influence of injection parameters on weight and part quality [8], investigating relationship between quality of holes drilled and the manufacturing factors in EBM drilling process [9] and so on.

2. EXPERIMENTAL PROCEDURE

2.1 Experimental plan

In this machining process, the final finish cutter form is reflected in the cavity, which is formed, in the component. Thus, for an intended depth of a broached part, the broach blade height setting should be adjusted accordingly. The cylindrical component has two diameters, outer and step. The CTQ wall thickness is measured from the step diameter as the reference. Therefore, variation in the step diameter will be reflected in wall thickness dimension. The component rests on the outer diameter in the fixture, thus having an effect on the broaching depth. Therefore, broaching blade setting height, outer diameter and step diameter are considered as control factors at two levels in the experiment. Outer diameter and step diameter levels have been selected as a range because it would take a lot of time to get exact dimensional combinations for conducting 112 experiments. So it was a more practical approach to trade off with ranges. The allowed tolerance zone of the specification limits is divided into two zones: high and low. It is desired to understand whether higher or lower tolerance zone in both the diameters is contributing towards the process variation.

The broaching machine has fourteen fixtures. Before selecting the DOE approach, exhaustive trial and error experiments were conducted to understand the fixture to fixture variation but there was no thorough conclusion. Therefore, it is desired to understand whether certain fixtures are contributing more to the variation than the others. In order to account for this, fixture is also taken as one of the control factors at fourteen levels. A full factorial general experimental design is created for the selected control factors i.e. outer diameter, step diameter, broaching blade height setting and type of fixture. The first three factors are taken at two levels and the fourth factor is taken at fourteen levels. The setting values at these levels are shown in Table 1.

Table 1: Process parameters with corresponding level settings

Factors	Levels	Values	
		Level 1	Level 2
Outer diameter	2	9.47 to 9.49	9.50 to 9.52
Step diameter	2	7.70 to 7.72	7.73 to 7.45
Broaching blade height setting	2	5.8	6
Fixture	14	1 to 14 in step of 1	

2.2 Experimental details

The experiment is conducted using a FIMAT linear horizontal broaching machine. The fourteen fixtures are attached to a continuous conveyor belt. The broach blades are fixed to the machine structure and the component is traversed in a linear motion through the blades. The component remains clamped inside the fixture during the broaching operation. Broaching experiments consisting of 112 trials based on general full factorial design with mixed levels were conducted to collect wall thickness measurement results on FIMAT broaching machine under wet cutting conditions. Six HSS cutting broach blades were used in series. The cylindrical components were turned from extrusion rods made of free cutting brass grade material. The CTQ is measured using a calibrated digital vernier caliper of mitutoyo make. Results are analyzed using minitab 17 software.

3. RESULTS AND DISCUSSION

3.1 Measurement results

Table 2: CTQ measurement results

Sr. No.	outer diameter	step diameter	broaching blade height setting	fixture	wall thickness	Sr. No.	outer diameter	step diameter	broaching blade height setting	fixture	wall thickness
1	1	1	1	1	0.6	57	2	1	1	1	0.86
2	1	1	1	2	1.45	58	2	1	1	2	1.35
3	1	1	1	3	1.45	59	2	1	1	3	1.37
4	1	1	1	4	1.45	60	2	1	1	4	1.44
5	1	1	1	5	1.4	61	2	1	1	5	1.3
6	1	1	1	6	1.45	62	2	1	1	6	1.37
7	1	1	1	7	1.4	63	2	1	1	7	1.41
8	1	1	1	8	1.44	64	2	1	1	8	1.49
9	1	1	1	9	1.42	65	2	1	1	9	1.4
10	1	1	1	10	1.45	66	2	1	1	10	1.39
11	1	1	1	11	1.04	67	2	1	1	11	0.97
12	1	1	1	12	1.34	68	2	1	1	12	1.32
13	1	1	1	13	1.34	69	2	1	1	13	1.35
14	1	1	1	14	1.37	70	2	1	1	14	1.35
15	1	1	2	1	0.55	71	2	1	2	1	0.6
16	1	1	2	2	1.37	72	2	1	2	2	1.36
17	1	1	2	3	1.25	73	2	1	2	3	1.2
18	1	1	2	4	1.37	74	2	1	2	4	1.42
19	1	1	2	5	1.39	75	2	1	2	5	1.3
20	1	1	2	6	1.33	76	2	1	2	6	1.31
21	1	1	2	7	1.4	77	2	1	2	7	1.32
22	1	1	2	8	1.22	78	2	1	2	8	1.29
23	1	1	2	9	1.28	79	2	1	2	9	1.35
24	1	1	2	10	1.24	80	2	1	2	10	1.24
25	1	1	2	11	1.07	81	2	1	2	11	1.08
26	1	1	2	12	1.36	82	2	1	2	12	1.27
27	1	1	2	13	1.36	83	2	1	2	13	1.27
28	1	1	2	14	1.31	84	2	1	2	14	1.27
29	1	2	1	1	0.42	85	2	2	1	1	0.37
30	1	2	1	2	1.45	86	2	2	1	2	1.35
31	1	2	1	3	1.27	87	2	2	1	3	1.3
32	1	2	1	4	1.51	88	2	2	1	4	1.41
33	1	2	1	5	1.33	89	2	2	1	5	1.39
34	1	2	1	6	1.55	90	2	2	1	6	1.48
35	1	2	1	7	1.28	91	2	2	1	7	1.45
36	1	2	1	8	1.4	92	2	2	1	8	1.37
37	1	2	1	9	1.4	93	2	2	1	9	1.56
38	1	2	1	10	1.33	94	2	2	1	10	1.42
39	1	2	1	11	1.08	95	2	2	1	11	1.11
40	1	2	1	12	1.33	96	2	2	1	12	1.38
41	1	2	1	13	1.3	97	2	2	1	13	1.3
42	1	2	1	14	1.41	98	2	2	1	14	1.32
43	1	2	2	1	0.48	99	2	2	2	1	0.85

44	1	2	2	2	1.24	100	2	2	2	2	1.41
45	1	2	2	3	1.23	101	2	2	2	3	1.38
46	1	2	2	4	1.28	102	2	2	2	4	1.39
47	1	2	2	5	1.32	103	2	2	2	5	1.22
48	1	2	2	6	1.33	104	2	2	2	6	1.36
49	1	2	2	7	1.45	105	2	2	2	7	1.42
50	1	2	2	8	1.35	106	2	2	2	8	1.31
51	1	2	2	9	1.29	107	2	2	2	9	1.31
52	1	2	2	10	1.34	108	2	2	2	10	1.43
53	1	2	2	11	0.96	109	2	2	2	11	1.18
54	1	2	2	12	1.3	110	2	2	2	12	1.23
55	1	2	2	13	1.39	111	2	2	2	13	1.26
56	1	2	2	14	1.28	112	2	2	2	14	1.37

The generalized full factorial experimental design and the measurement results are summarized in Table 2. In this study, ANOVA was carried out to examine the influence of process parameters on quality characteristic.

3.2 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) tests the hypothesis that the means of two or more populations are equal. ANOVA on wall thickness measurement is summarized in Table 3, it can be concluded with 95% confidence level that broaching blade height and fixture are statistically significant factors. It is also observed that outer diameter and step diameter are non-significant as p value is greater than 0.05. The interaction factors are non-significant as well.

Table 3: ANOVA of CTQ measurement

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	58	5.18847	0.089456	14.11	0.000
Linear	16	4.92086	0.307554	48.49	0.000
outer dia	1	0.00300	0.003004	0.47	0.494
step dia	1	0.00013	0.000129	0.02	0.887
broaching blade height setting	1	0.08580	0.085804	13.53	0.001
fixture	13	4.83192	0.371686	58.61	0.000
2-Way Interactions	42	0.26761	0.006372	1.00	0.489
outer dia*step dia	1	0.01956	0.019557	3.08	0.085
outer dia*broaching blade height setting	1	0.00489	0.004889	0.77	0.384
outer dia*fixture	13	0.07842	0.006032	0.95	0.509
step dia*broaching blade height setting	1	0.01463	0.014629	2.31	0.135
step dia*fixture	13	0.05575	0.004288	0.68	0.777
broaching blade height setting*fixture	13	0.09437	0.007259	1.14	0.345
Error	53	0.33613	0.006342		
Total	111	5.52460			

If some parameters do not significantly affect the CTQ, they can be ignored and excluded from predictive model generation and the optimization process. This will increase the efficiency of the optimization process [10]. Therefore, ANOVA is repeated again ignoring all the non-significant factors, refer Table 4.

Table 4: ANOVA on significant effects

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	4.91773	0.351266	56.15	0.000
Linear	14	4.91773	0.351266	56.15	0.000
broaching blade height setting	1	0.08580	0.085804	13.71	0.000
fixture	13	4.83192	0.371686	59.41	0.000
Error	97	0.60687	0.006256		
Total	111	5.52460			

From Table 4, it can be observed with 95% confidence level, that broaching blade height setting and fixture are statistically significant factors that affect the wall thickness. The main effect plot in Fig.1 shows the effect on wall thickness as the control factors vary across the levels. From main effect plot it can be seen that the blade height setting does not vary significantly across level 1 and level 2. It is also observed that the average wall thickness reading at fixture 1 and fixture 11 is 0.59 and 1.04, respectively. These readings are far below LSL and increase the variation in the experiment. For further improvement in the process, these fixtures are shortlisted for correction. The root cause behind the significant variation is found to be error in clamping the component in the fixture. Upon investigation, it was observed that during clamping the component gets lifted and sits cross in the fixture such that the wall thickness reduces drastically. This is a special cause for variation. After this was identified, the fixtures were corrected for clamping mechanism by replacing the worn out parts. The fixtures were reconditioned and all were tested for clamping position when the confirmation experiment was conducted.

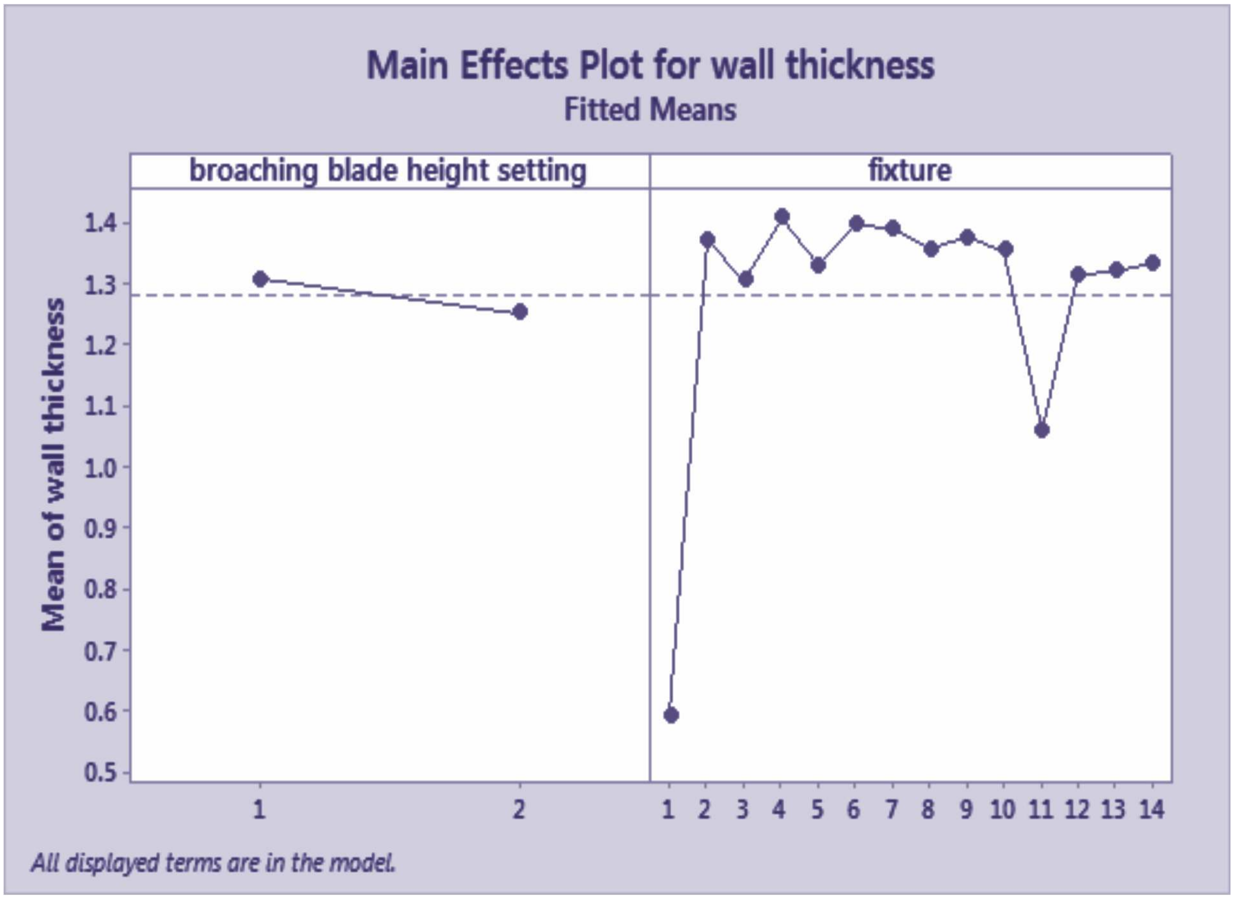

Fig 1: Main effect plot

3.2 Regression Analysis

The relationship between the independent variable and response variable is characterized by the mathematical model called a regression model. The regression model is a fit to a set of sample data [11]. The R sq (adj) value of the following regression model is 87.43%.

wall thickness = 1.28018 + 0.02768 broaching blade height setting_1 - 0.02768 broaching blade height setting_2 - 0.6889 fixture_1+ 0.0923 fixture_2 + 0.0261 fixture_3 + 0.1286 fixture_4 + 0.0511 fixture_5+ 0.1173 fixture_6 + 0.1111 fixture_7 + 0.0786 fixture_8 + 0.0961 fixture_9+ 0.0748 fixture_10- 0.2189 fixture_11 + 0.0361 fixture_12+ 0.0411 fixture_13 + 0.0548 fixture_14 (1)

4. CONFIRMATION EXPERIMENT

After the fixtures were reconditioned, confirmation experiment was conducted to verify the stability of the broaching process. The blade height setting control factor was set at level 2. The process capability and the process capability index were found to be 1.76 and 1.66, respectively based on 112 trials and subgroup size 8. This confirms the process was stabilized and improved. The histogram plot of the confirmation experiment is shown in Fig 2. It can be seen that the process mean is very close to the target value. Therefore, the process was successfully optimized using the DOE approach.

5. CONCLUSION

In this study, DOE approach was applied to optimize the broaching process. Regression analysis was performed to find whether the experimental measurements represent a fitness characteristic for the optimization process. Confirmation experiment was conducted to verify the improvement in process capability. ANOVA results showed that broaching blade height setting and fixtures were statistically significant factors with alpha equal to 0.05. Fixture 1 and Fixture 11 were analyzed to identify the special cause of variation and it was observed that components got clamped in a lifted position such that it was not resting on its outer diameter. As the amount of lifting was not consistent, therefore the variation in wall thickness was also significant. The identified fixtures were taken for reconditioning. The worn out parts were replaced. Clamping condition was tested for all 14 fixtures after improvement.

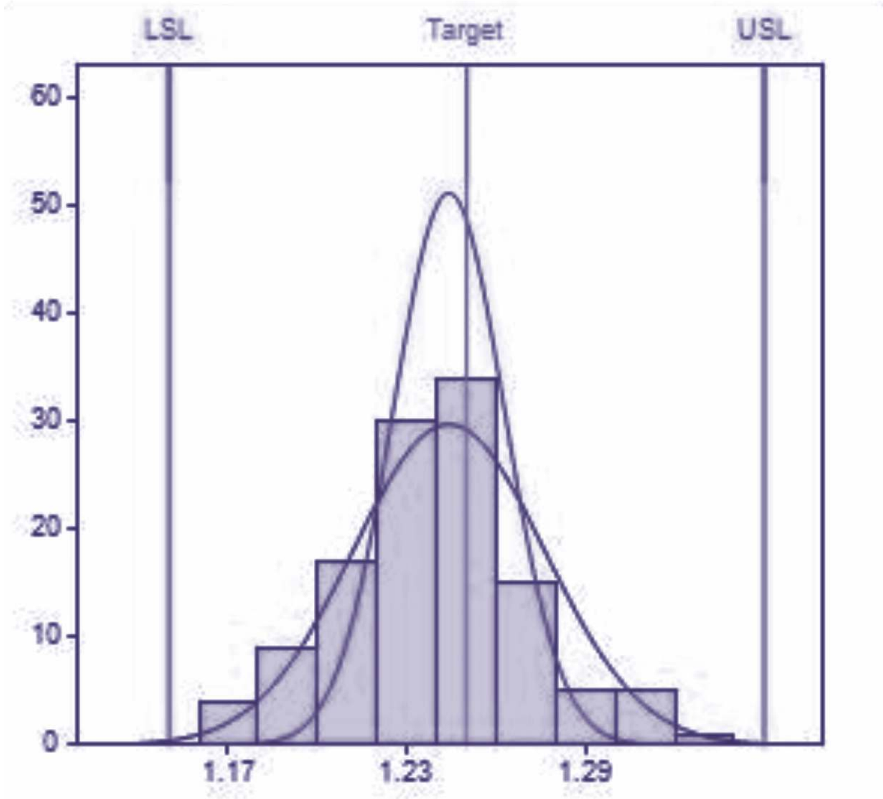

Fig 2: Histogram and Process capability curve for wall thickness

In the multiple regression analysis, R sq. (adj.) value was found to be 87.43% that is greater than 80%. It is clearly seen that the quality characteristic data measured from the experiments is representative of the relation between response variable and control factors. The confirmation experiment verified the improvement in process capability index from 0.68 to 1.66, thus, reducing rejection level from 4.6% to 0.6% at the conclusion of the study.

REFERENCES

1. *M.P. Groover, Fundamentals of modern manufacturing, 4th Edition, (John Wiley & Sons Inc., 2010), pp. 507-577.*
2. *D. Fabre, C. Bonnet, J. Recha and T. Mabrouki, Optimization of surface roughness in broaching, CIRP Journal of Manufacturing Science and Technology, in press, (2016).*
3. *T. Mabrouki, C. Courbon, D. Fabre, I. Arrieta, P.-J. Arrazola and J. Rech, Influence of Microstructure on Chip Formation when Broaching Ferritic-Pearlitic Steels, Procedia CIRP 58, (2017) pp. 43-48.*
4. *F. Klocke, B. Döbbeler, M. Seimann, Dry Broaching Using Carbon Free Steel as Tool Material, Procedia CIRP 46, (2016), pp. 496-499.*
5. *N.R. Tague, The Quality Toolbox, second edition (ASQ Quality Press, 2005), pp. 225-233.*
6. *D.C. Montgomery, Design and analysis of experiments, Eighth edition (2017), pp. 449-475.*
7. *G.O. Verrana, R.P.K. Mendes, L.V.O. Dalla Valentina, DOE applied to optimization of aluminum alloy die castings, Journal of materials processing technology (2008), pp. 120–125.*
8. *A. López, J. Aisa, A. Martinez, D. Mercado, Injection moulding parameters influence on weight quality of complex parts by means of DOE application: Case study, Measurement, Volume 90, (2016), pp. 349-356.*
9. *P. C. Priarone, S. Ruffa, J. S. Bedolla, L. Settineri, A DoE approach to hole quality evaluation in drilling of an electron beam melted titanium aluminide, Procedia CIRP 8, (2013), pp. 481-486.*
10. *H. Oktem, T. Erzurumlu, M. Col, A study of the Taguchi optimization method for surface roughness in finish milling of mold surfaces, International Journal of Advanced manufacturing technology, (2006), 28: pp. 694–700.*
11. *T.M. Kubiak, D.W. Benbow, The Certified Six Sigma Black Belt handbook, (ASQ Quality Press, 2012), pp. 167-181; 294-325.*

AUTHORS

Ms. Jaya Valyan, Student ME, Industrial Engineering, Goa College of Engineering, Farmagudi, Ponda, Goa – 403 401
E-mail: jayavalyan4@gmail.com

Dr. Suraj Rane, Professor, Mechanical Engineering Dept., Goa College of Engineering, Farmagudi, Ponda, Goa – 403 401
E-mail: ssr@gec.ac.in